International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 19 (2017) pp. 8609-8614
© Research India Publications. http://www.ripublication.com

Linear Precoding using Transmitter Site Channel Estimation for MIMO-OFDM systems

R. Raja Kumar
Professor, Department of Mathematics,
Sathyabama University, Chennai-119, Tamil Nadu, India.

Orcid ID: 0000-0002-2695-9813

P. Indumathi
Associate Professor, Department of Electronics Engineering
MIT Campus, Anna University, Chennai-44, Tamilnadu, India.

Orcid ID: 0000-0002-3905-8336

Abstract

Orthogonal Frequency Division Multiplexing is an approach that can be used to combat the effect of frequency selective fading channels. Apart from spectral efficiency, reliability over fast fading channels is a primary concern in OFDM. MIMO systems offer a solution to this problem owing to the high capacity and beamforming gain. The integration of MIMO with the traditional OFDM systems allow parallel transmission of data with significant reduction in inter-carrier interference. The tradeoff to be considered is the increase in complexity of the user equipment. This is due to the advanced modulation and estimation operations performed at the receiver. In this paper, we present a transmitter site channel estimation scenario with the help of pilot symbols. Further, a MIMO-OFDM transceiver is designed which utilizes the information of the channel state at the transmitter to perform SVD based linear precoding on the data. Such a type of precoding scheme provides reduction in bit error rate to an optimum range. The simulation results show that a singular value based precoding technique performs better than the traditional Alamouti space time block code. But the requirement of additional time slot for channel estimation is a challenge that accompanies this technique.

Keywords: MIMO-OFDM, SVD, Alamouti Coding, QR Precoding, MMSE.

INTRODUCTION

Current generation wireless systems heavily rely on MIMO technology for obtaining higher data rate and increased SNR for data transmission. As the number of antennas at the receiver side increases, the diversity order increases proportionally. There has been considerable attention given to the capacity and performance of MIMO systems with varying degrees of CSI available at the transmitter. However, less attention has been given to the methods used for obtaining this information at the transmitter. Here, Thiagarajan proposed a novel transmit precoding technique in order to increase the diversity.

Work outline

Objective

To design a MIMO OFDM transceiver and perform channel estimation at the transmitter site and analyze the performance for different modulation schemes like BPSK, QPSK, 16-QAM using precoding techniques like SVD, Alamouti coding and QR based schemes. Also, to plot the capacity curve and calculate the time complexity of various estimation techniques.

Motivation

Multiple antenna technologies enable high capacities, high data rates, high range and reliability suited for increasing demand of Internet and multimedia services. The current research in MIMO places emphasis on realizing the theoretical gains and practical implementation of these systems.

Organization of the paper

This paper consists of the literature existing for the possibility of the transmitter site estimation. Further, an implementation of the system using precoding to further decrease the error rate highlights the necessity to move towards such a system.

RELATED WORK

Literature Survey

The idea of basic wireless communications is explained by Theodore S.Rappaport in [11]. The basics of multiple element antennas (MEA) is explained by Molisch in [10]. Helmut Bolcskei [3] proposed that MIMO technology will predominantly be used in broadband systems that exhibit frequency-selective fading and, therefore, inter symbol interference (ISI). OFDM modulation turns the frequency-selective channel into a set of parallel flat fading channels and is, hence, an attractive way of coping with ISI. Jubin Jose et. al [9] suggested the idea of exploiting the reciprocity of the channel in TDD systems. In particular, with the increasing number of base-station antennas, the TDD operation helps in improving the effective forward channel without affecting the training sequence length required. Ganesan Thiagarajan et. al [12] provided that infinite diversity order can be achieved when the CSI(Channel State Information) is available only at the transmitter. A novel transmit precoding based on QR decomposition with number of transmit antennas being twice as that of receive antennas is developed. The numerical results illustrate that the CSIT based transmission schemes offer better performance in terms of BER as compared to CSIR based schemes. Zheng and Tse [15] found in this work that, for Rayleigh fading MIMO channels with perfect CSIR, the maximum diversity order can at most be N_r*N_t, where Nr and N_t denote the number of antennas at the receiver and transmitter, respectively. Since that early result, Diversity multiplexed gain tradeoff (DMT) has been extended to various cases with full/partial knowledge of CSI at the transmitter (CSIT) and receiver (CSIR), and various multiuser channels. However, transmit diversity schemes, and the corresponding achievable DMT, of a fading MIMO channel with CSI available only at the transmitter and no CSIR has received relatively little attention in the literature. M. Guillaud [6] et. al described that the acquisition of CSIT has typically been viewed as a two-stage process: CSI is first acquired at the receiver using a known training sequence in the forward-link direction, and then fed back from the receiver to the transmitter over the reverse-link in a quantized or analog fashion. Thus, the existing studies inherently assume an initial estimation of CSI at the receiver. However, when the channel is reciprocal, i.e., when the forward and reverse channels are the same, CSI can be directly acquired at the transmitter by sending a known training sequence in the reverse-link direction. The channel can be modeled as being reciprocal, for example, in Time Division Duplex (TDD) communication systems.

System Model

The model considered here is a 2x2 MIMO OFDM system with channel estimation at the transmitter side as described in Fig 1.

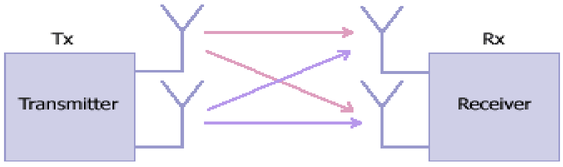

Figure 1. A Simplified 2x2 MIMO System.

The channel is estimated using the pilot symbol transmission. Binary Phase Shift Keying Modulation is used for ubiquitous transmission of pilot symbols. This is because BPSK allows higher accuracy required for exact estimation of channel properties. An adaptation function f is designed which adapts to the channel, h. An inverse filter f^{-1} has a frequency response of F^{-1}. Thus, each of the incoming pilot is multiplied by this factor and then transmitted to the receiver. In essence, this pre-distortion type adaptive equalization nullifies the effect of the channel as illustrated in Fig 2 and Fig 3.

Some of the assumptions taken into account are that channel is a mirror channel. This means that channel properties like path loss and fading are same for both forward and the reverse channel. Also, the channel is assumed to be slow fading. Hence, the response of the channel is constant for a given coherence time.

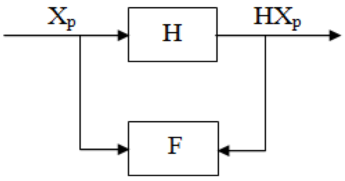

Figure 2. Adaptation Function.

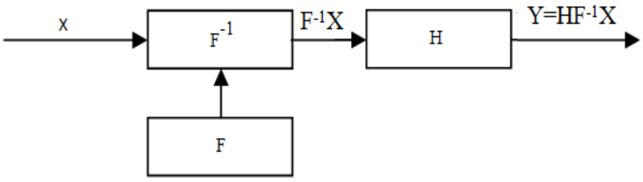

Figure 3. Data Symbols Transmission.

Estimation Algorithms and Precoding

Zero Forcing

The zero forcing based estimation algorithm is simplest but provides the least performance when compared to other techniques. First the pilot bits are transmitted from the receiver to transmitter. Since this information is known at both sides, the received signal can be considered to have similar properties of the channel, thus providing the instantaneous channel response. The mathematical representation can be provided as,

$$y=Hx + n$$

where H is the channel response and y is the received signal. To solve this equation, we estimate a matrix M, which is the pseudoinverse matrix such that,

$$M^*H = I$$

This constraint can be met by the following linear estimator.

$$\begin{pmatrix} \mathbf{h}^*_{1,1} & \mathbf{h}^*_{2,1} \\ \mathbf{h}^*_{1,2} & \mathbf{h}^*_{2,2} \end{pmatrix} \begin{pmatrix} \mathbf{h}_{1,1} & \mathbf{h}_{1,2} \\ \mathbf{h}_{2,1} & \mathbf{h}_{2,2} \end{pmatrix} = \begin{pmatrix} |\mathbf{h}_{1,1}|^2 + |\mathbf{h}_{2,1}|^2 & \mathbf{h}^*_{1,1}\mathbf{h}_{1,2} + \mathbf{h}^*_{2,1}\mathbf{h}_{2,2} \\ \mathbf{h}^*_{1,2}\mathbf{h}_{1,1} + \mathbf{h}_{2,1}\mathbf{h}^*_{2,2} & |\mathbf{h}_{1,2}|^2 + |\mathbf{h}_{2,2}|^2 \end{pmatrix}$$

Minimum Mean Square Estimation(MMSE)

This type of estimator is similar to zero forcing but an additional term for noise variance is added. As a result, the bit error rate reduces to an extent. In this estimation,

$$M = (H^H H + N_0 I)^{-1} H^H$$

where H^H is the hermitian transpose of the channel matrix. From the above equation it is clear that this equation is different from the equation of zero forcing equalizer by the term NoI. If NoI=0, in this equation, then MMSE equalizer becomes zero forcing equalizer.

Maximum Likelihood Estimation

The ML based channel estimation produces the best performance in terms of error. But, for higher order modulation techniques, a larger code book design is required. Also, the comparison of the data for each symbol detection provides an increased level of system complexity.

$$\mathbf{J} = \left\| \begin{pmatrix} \mathbf{y_1} \\ \mathbf{y_2} \end{pmatrix} - \begin{pmatrix} \mathbf{h_{1,1}} & \mathbf{h_{1,2}} \\ \mathbf{h_{2,1}} & \mathbf{h_{2,2}} \end{pmatrix} \begin{pmatrix} \mathbf{x_1} \\ \mathbf{x_2} \end{pmatrix} \right\|^2$$

ML scheme computes J for every possible combination of symbol values. These element values have to be stored and the minimum value among these gives an accurate estimate of the received signal.

QR Based Estimation

In this system, the channel matrix is to decompose to QR form. The desired signal from transmitting antenna can be found based on the least square approximate solution. The detected desired signal x_{qlqr} is computed as

$$x_q=((R^H R + \sigma^2 I)^{-1} H^H)^* y$$

$$r=y-H^* x_q$$

$$e=((R^H R + \sigma^2 I)^{-1} H^H)^* r$$

$$x_{qlqr} = x_q + e$$

This system provides a better performance compared to other systems except ML. However, the simplicity in terms of complexity and design makes this an attractive option for MIMO based data transfer techniques.

Precoding

Singular Value Based Precoding

Once the channel from the receiver to transmitter is estimated, assuming that it is a reciprocal channel, singular value decomposition is performed on the channel values. Thus, matrices U, ∑ and V are obtained. Here, ∑ is the diagonal matrix which converts the Rayleigh channel to parallel flat fading channel matrix thus increasing the diversity.

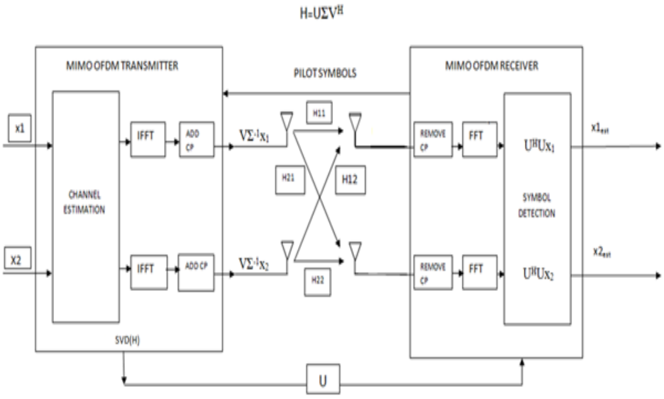

Figure 4. Precoding using SVD.

Figure 4. illustrates the system model considered. Here a 64 point FFT is performed in each of the transmit antenna. The matrix U has to be known at the receiver. This results in a separate transmission of this matrix and detection at the receiver.

Alamouti Based Precoding

The traditional Alamouti [2] based precoding scheme is considered. One of the major problems with regard to the inefficiency of the Alamouti scheme is that it requires two-time slots to transfer two symbols. It requires transmission of symbols x_1 and x_2 in the first slot and $-x_2^*$ and x_1^*in the next. On combining the matrix values for symbols in two-time slots, the H matrix is obtained as,

$$\boldsymbol{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{12}^* & -h_{11}^* \\ h_{22}^* & -h_{21}^* \end{bmatrix}.$$

The estimate of the symbols is

$$\widehat{\begin{bmatrix} x_1 \\ x_2^* \end{bmatrix}} = (H^H H)^{-1} H^H \begin{bmatrix} y_1^1 \\ y_2^1 \\ y_1^{2*} \\ y_2^{2*} \end{bmatrix}$$

The pseudoinverse can be performed by any of the estimation techniques.

QR Based Precoding

A novel QR based precoding is presented in [12]. However, this scheme can be applicable for systems with $N_t = 2xN_r$. An adaptation of this scheme provides a solution for a general case. The algorithm is as follows.

```
Algorithm – QR – Precoding
Inputs: $H \in C^{Nt \times Nr}$, data $x \in C^{Nr}$, unitary $U \in C^{Nt \times Nt}$, transmit power
Outputs: Transmit signal $s \in C^{Nt}$
Start:
        Compute QR decomposition $\mathbf{H} = \mathbf{QR}$
        Partition $\mathbf{R} = [\mathbf{R_1}^{\mathbf{H}}\ \mathbf{0}^{\mathbf{H}}_{(Nt-Nr)\times Nr}]^{\mathbf{H}}$,
        where $\mathbf{R_1} \in C^{Nr \times Nr}$
        Compute $\mathbf{x'} = \mathbf{R_1}^{-\mathbf{H}}\mathbf{x}$,
        and $x^{H} = [x'^{H}\ x'^{H}\ 0^{H}_{Nt-2Nr}]$
        Compute $\mathbf{P} = \mathbf{QU}$
        Compute transmit signal $s = \sqrt{\mathbf{1/Nt}}\ \mathbf{Px}$
End
```

Once the transmit signal is computed for each antenna, a separate signal Q has to be transmitted to the receiver. On reception of the data a simple inverse operation of Q provides the reconstruction of the required symbol. This is described in Figure 5.

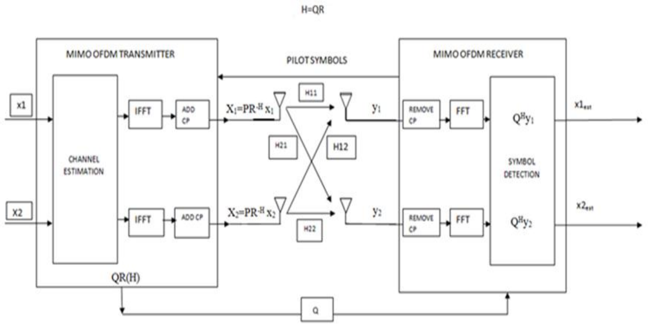

Figure 5. Precoding using QR.

RESULTS AND DISCUSSION

The channel is assumed to be TDD and the simulation is done for 2x2 MIMO OFDM system. The modulation schemes used are BPSK, QPSK, 16-QAM. The results are obtained for various channel estimation algorithms.

It is found that maximum likelihood estimation has the highest accuracy. The QPSK and 16-QAM modulation schemes use a look up table at the receiver end to demap the signal into bits. As a result, in the practical transmission of data, appropriate power levels have to be considered. The voltages under consideration should not be very close because variations in noise level would lead to erroneous detection. However, large differences lead to transmission of very high power which may cause heating of the mobile system. The table I provides the simulation parameters of the OFDM system.

Table 1. OFDM System Parameters

Number of subcarriers	64
Channel	Rayleigh Fading Channel
OFDM Bandwidth	20MHz
Bandwidth/ Carrier	3.125MHz
OFDM Symbol Period	3.2µs
Cyclic Prefix Period	0.8µs
BER (at 15 dB)	0.145

Table 2. MIMO OFDM Parameters for 16-QAM Modulation

Number of data bits	$8x10^4$
Bits/Symbol	1
Channel/Noise	Rayleigh/AWGN
BER for Zero Forcing(at 14 dB)	$4\ x10^{-2}$
BER for MMSE (at 14 dB)	$2.8x\ 10^{-2}$
BER for Q less QR (at 14 dB)	$2.2\ x10^{-2}$
BER for MLD (at 14 dB)	$1.2\ x\ 10^{-4}$

Table 3. MIMO OFDM Parameters for different Precoding

Number of data bits	$8x10^4$
Bits/Symbol	1
Channel/Noise	Rayleigh/AWGN
BER for SVD Precoding (at 13 dB)	$3.8\ x\ 10^{-4}$
BER for Alamouti Precoding (at 13 dB)	$6\ x\ 10^{-3}$
BER for QR based recoding (at 13 dB)	$9\ x\ 10^{-5}$

The Table 2 lists the MIMO OFDM parameters for 16-QAM and Table 3 lists the MIMO OFDM parameters for different precoding techniques.

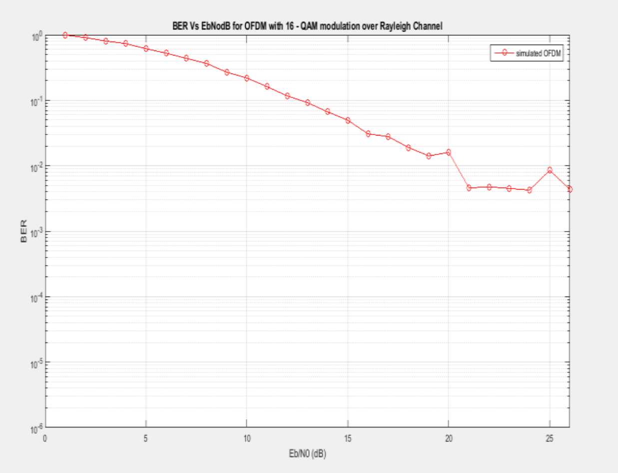

Figure 6. BER vs SINR for OFDM modulation scheme.

From the graph, we infer that although OFDM provides a better BER performance when compared to the conventional FDM systems due to the orthogonality of subcarriers and introduction of cyclic prefix, a BER of 0.145 cannot be accepted for practical standards. This is the reason why we try to incorporate MIMO with the OFDM systems.

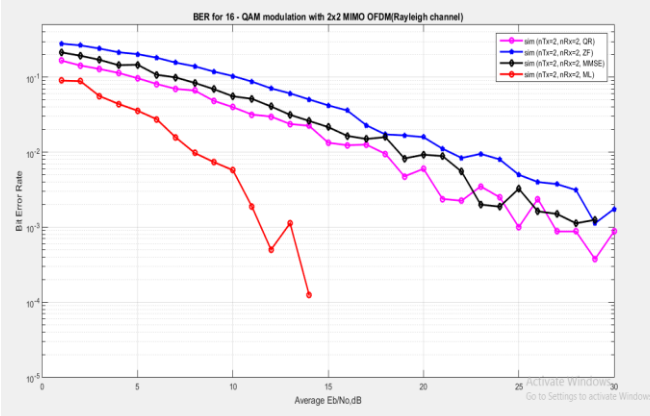

Figure 7. BER vs SINR for MIMO OFDM 16-QAM Modulation

From Figure 7. it is observed that the BER gradually increases with every modulation technique. This is because, for schemes like QAM, a single bit error leads to a burst error due to erroneous detection of the symbols. However, during practical scenarios, we use higher order modulation schemes due to the increase in data rate that they provide. Television systems employ transmission schemes like 256-QAM. This is also the reason why BPSK is used for transmission of pilot symbols. As pilots are used to ascertain the properties of the channel, high degree of accuracy is required which can be compromised in the data rate.

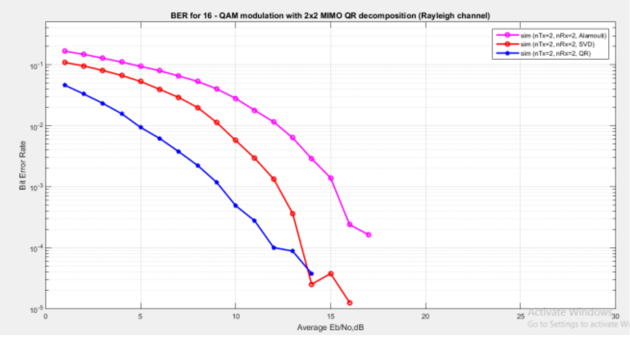

Figure 8. BER vs SINR for Different Precoding Techniques under 16- QAM

Having obtained the channel properties, precoding is employed to further decrease the BER. The proposed QR based precoding offers a better performance against the SVD and conventional Alamouti Space Time Coding Schemes. A theoretical BER of about 9 x 10^{-5} is achieved by this scheme.

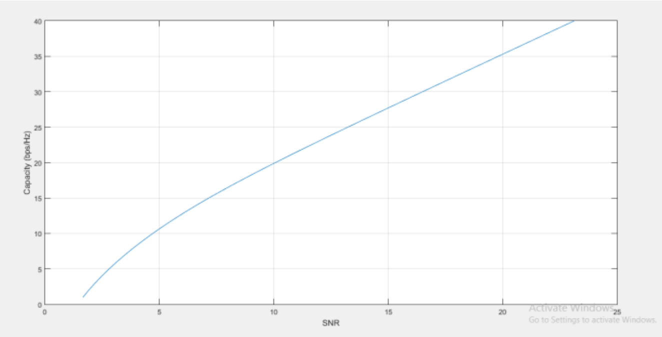

Figure 9. Capacity vs SINR for 2x2 MIMO OFDM system

The capacity plot is obtained through the following formula for flat fading MIMO channel system.

$$C = \log\left(\det\left(I_{NT} + (\gamma/N_T)\ HH^H\right)\right) \tag{1}$$

For, a practical SNR range of 20 dB, a capacity of 35 bps/Hz is obtained for our 2x2 MIMO OFDM system.

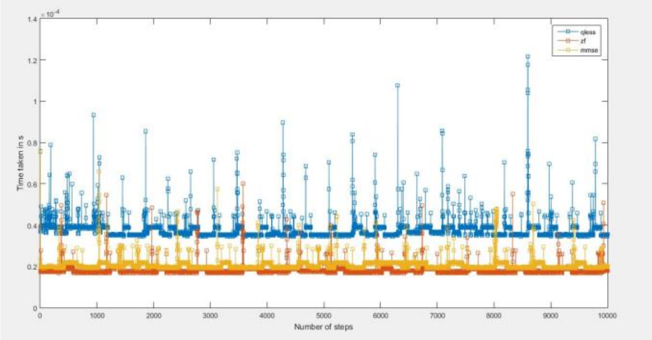

Figure 10. Time Complexity for the various iterations of Zero Forcing, MMSE and Q less QR based decomposition

CONCLUSION

The time complexity of the estimation techniques is obtained by finding the computational time of each technique. From the above graph, it is found that Zero Forcing algorithm takes the least time to compute, while ML detection takes the most. Also, MMSE takes lesser time to compute compared to Q less QR technique. However, considering the optimal performance, Q less QR technique offers better Bit Error Rate (BER). It can be observed that the use of precoding greatly reduces the BER but comes with an additional complexity due to an extra hardware required at the transmitter. From a BER of 2.2 x 10^{-2} by using the 16-QAM, it is possible to achieve a theoretical BER of 9 x 10^{-5} at a SINR of 14 dB. Of all the estimation techniques, Q less QR based estimation offers an optimal BER. The Maximum Likelihood detection scheme suffers from the drawback that a large codebook is required at the transmitter, consuming more time than other schemes. The capacity of the MIMO OFDM system is found out to be 35 bps/Hz at an SNR of 15 dB. The time complexity of Q less QR scheme is approximately equal to 0.4 x 10^{-4} s which is higher than that of other techniques.

REFERENCES

[1] Akash Mohan, Amrita Mishra, Karthik M, Padma N, Prashanth G, Deepa R, “A Novel Pre-Distortion type Adaptive Channel Equalisation Technique for SISO”, International Conference on Emerging Trends in Electrical and Computer Technology (ICETECT’11), ISBN: 978-1-4244-7925-2, pp 1047-1050, March 2011.

[2] Alamouti .S.M,” A simple transmit diversity technique for wireless communications” IEEE Journal on Selected Areas in Communications (Volume:16 , Issue 8).

[3] Allan Lopes and Zahir Aalam , “Performance Analysis and Hardware Implementation of a 802.lln 4X4 MIMO OFDM Transceiver Using 16-QAM”, International Journal of Advanced Information Science and Technology (IJAIST) Vol.27, No.27, July 2014.

[4] Cortes-Pena .L, “Orthogonal Space-Time Coding Matlab Source Files,” Software online: http:// users.ece.gatech.edu/_Cortes/STBC Matlab.html, 2009.

[5] David Gesbert, “From Theory to Practice: An Overview of MIMO Space–Time Coded Wireless Systems”, IEEE Journal On Selected Areas In Communications, Vol. 21, No. 3, April 2003.

[6] M. Guillaud, D. T. M. Slock, and R. Knopp, “A practical method for wireless channel reciprocity exploitation through relative calibration,” in Signal Processing and Its Applications, 2005. Proceedings of the Eighth International Symposium on, vol. 1, 2005, pp. 403–406

[7] Helmut Bolcskei,“Mimo - Ofdm Wireless Systems: Basics, Perspectives, And Challenges”, August 2006.

[8] Hochwald .B. M and T. L. Marzetta, “Unitary Space–Time Modulation for Multiple-Antenna Communications in Rayleigh Flat Fading”, IEEE Trans. Inf. Theory 46 (2), pp.543–564, 2000.

[9] Jubin Jose, Alexei Ashikhmin, Phil Whiting, Sriram Vishwanath “Channel Estimation and Linear Precoding in Multiuser Multiple-Antenna TDD Systems”, IEEE Transactions on Vehicular Technology, Vol. 60 Issue 5, April 2011.

[10] Molisch .A, Wireless Communications. Wiley-IEEE Press, 2005.

[11] Theodore. S. Rappaport, Wireless Communications: Principles and Practice (2nd edition), Pearson India 2010

[12] Thiagarajan .G et al, “Novel Transmit Precoding Methods for Rayleigh Fading Multiuser TDD-MIMO Systems With CSIT and No CSIR”, IEEE Transactions on Vehicular Technology, Volume:64 , Issue: 3, pp 973-984, March 2015.

[13] Thiagarajan .G et al,” Novel precoding methods for Rayleigh fading Multiuser TDD-MIMO systems”, IEEE International Conference on Communications, pp- 5586-5591, 10-14 June 2014.

[14] Tse .D and Viswanath .P, ”Fundamentals of Wireless Communication” , Cambridge University Press, 2005.

[15] L. Zheng and D. Tse, “Diversity and multiplexing: A fundamental tradeoff in multiple-antenna channels,” IEEE Trans. Inf. Theory, vol. 49, no. 5, pp. 1073–1096, May 2003

[16] M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.